A LAKE BREEZE INDEX

by

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ABSTRACT

Since the mathematical equations describing the lake breeze phenomenon are too complex to yield exact solutions, approximation techniques are often used. To obtain the important parameters upon which the solutions depend, a dimensional analysis is then employed. The study shows that two dimensionless parameters describe the balance of forces that distinguish between lake breeze days. A lake breeze index is established and a critical value is found. If a narrow transition zone is recognized, then the lake breeze index has an accuracy of 97 per cent.

ACKNOWLEDGMENTS

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1. INTRODUCTION

The physical concept of a lake breeze may be stated as a heat transfer problem. During periods of insolation the land surface is heated and its temperature increases, whereas the water surface remains at a relatively constant temperature due to its thermal characteristics. The surface temperature influences the overlying air and as a result there is warmer and less dense air over land while over the water the overlying air is cooler and more dense. Near the shore line between the two surfaces, a pressure gradient is established due to the buoyant effects created by the temperature differences. Thus if the prevailing synoptic conditions are such that the gradient wind is light, the buoyant force is the dominant force and a lake breeze is established.

The equation of motion, the energy equation, and the equation of continuity are used to establish the general properties of the motion and to calculate the unknown physical variables [2,3,4,5,7]. However, the problem formulated in exact mathematical terminology is too complex to solve analytically. The results of a theoretical analysis then depend

on approximate equations. An investigation of this character should be initiated by finding out the important mathematical relationships between the properties that govern the phenomenon. A preliminary analysis and choice of a system of nondimensional parameters is made possible by dimensional analysis and similarity theory.

2. DEVELOPMENT OF A LAKE BREEZE INDEX

Consider that the following function of fundamental quantities describes the lake breeze

$$\Phi = f(U, \ell, h, \beta, K_m, C_p, k, \rho, T, \Delta T, p, g)$$

Φ = a function that describes the lake breeze

U = a characteristic velocity

ℓ = a characteristic length

h = a characteristic height

β = coefficient of expansion of air

K_m = eddy diffusivity

C_p = heat capacity of air

k = thermal conductivity of air

ρ = density

T = a characteristic temperature

ΔT = difference between the characteristic temperature and the lake temperature

p = pressure

g = gravity

Application of Buckingham's Theorem [9] yields the following quantities

$$\frac{h}{\ell} = \varphi \left[\frac{\Delta T}{T} , \frac{U^2}{C_p T} , \frac{kT}{U^3 \ell \rho} , \beta T , \frac{U\ell}{K_m} , \frac{p}{\rho U^2} , \frac{g\ell}{U^2} \right]$$

Motions which are caused primarily by the density gradients created by temperature differences are termed "natural" as distinct from those "forced" on the stream by external causes. In natural flows, the Reynolds number, $U\ell/\nu$ $(= U\ell/K_m \cdot K_m/\nu)$, where ν is the kinematic viscosity, and the Euler number, $p/\rho U^2$, are of little importance because the solutions are nearly independent of their values. Thus they can be neglected when compared to the other quantities.

The Prandtl number, $\mu C_p/k$, where μ is the dynamic viscosity, and the Grashof number, $g \beta T \ell^3/\nu^2$, can be

obtained by suitable combinations of the above parameters. The Prandtl number is practically constant for air $(P = 0.7)$, so it is neglected. The Grashof number is considered important [8] in natural flows, so it is retained.

Thus the important ratios are

$$\frac{h}{\ell} = \varphi\left[\frac{\Delta T}{T}, \frac{U^2}{C_p T}, \frac{kT}{U^3 \ell \rho}, \frac{g\ \beta\ T\ \ell^3}{K_m^{\ 2}}\right]$$

Special attention is called to two parameters, namely, $U^2/C_p T$ and $\Delta T/T$, which contain readily measurable quantities. C_p for air is 1.003 joules/gm °K. T and U are obtained by selecting a site uninfluenced by the lake breeze effect and therefore representative of the temperature and wind velocity for the local area. ΔT is simply the difference between the land temperature and the lake water temperature.

Dividing $U^2/C_p T$ by $\Delta T/T$ gives a new parameter, $U^2/C_p \Delta T$. This parameter is the dominant one, since it combines the two most important variables, wind speed and temperature difference. A closer inspection shows this to be a ratio between the inertial force and the buoyancy force. The inertial force is given by the wind speed and the buoyancy force is given by the temperature difference. The writers have termed this ratio

of forces the "Lake Breeze Index" (hereinafter referred to as the "L-B Index").*

The L-B Index expresses a relationship between the inertial and buoyancy forces and determines which is dominant. Thus, if the inertial force is relatively large, it can be asserted that there will not be a lake breeze. If, however, the buoyancy force becomes large, the stage is set for the establishment of a lake breeze. The critical value and the limitations of the L-B Index will now be explored.

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*The dimensionless ratio, $U^2/C_p \Delta T$, was referred to by Schlichting [8] as the Eckert number, following a suggestion by Professor E. Schmidt. However, in that case it was used to show that the frictional heat and the heat due to compression was important for the calculation of the temperature field when the free stream velocity, U_∞, was so large that the adiabatic temperature increase was of the same order of magnitude as the prescribed temperature difference between the body and the stream. Thus,

$$U_\infty{}^2/C_p(\Delta T)_o = 2\,(\Delta T)_{ad}/(\Delta T)_o$$

where

$(\Delta T)_o$ = the temperature difference between the body and the stream

$(\Delta T)_{ad}$ = the temperature change due to compression of the high speed flow

The work of compression and that due to friction become important when the free-stream velocity is comparable to the speed of sound. Therefore, the above interpretation of the Eckert number is not relevant to the present study.

3. A CRITICAL LAKE BREEZE INDEX

In finding the critical value separating lake breeze days from non-lake breeze days, a previous statistical analysis [6] of two months (June and July, 1957) of climatological data from the Enrico Fermi Nuclear Reactor site located on the western shore of Lake Erie (Fig. 1) was used as a verification criterion and the L-B Index was compared to it. A critical value of three was chosen since all days with a L-B Index greater than three were seen to be non-lake breeze days and all days when the L-B Index was between zero and three were lake breeze days.

To test the system, information gathered during the following months was used as independent data: May and August, 1957; May, June, July and August, 1958 and 1959. To compute the L-B Index, a maximum temperature and mean daytime wind speed were sought which were representative of conditions near the lake shore with the lake effect removed. A desirable source seemed to be Detroit Metropolitan Airport, which is located about 19 mi NNW of the reactor site. However, hourly observations from Detroit Metropolitan only dated back to the fall of 1958, so the Willow Run Airport just east of Ypsilanti, Michigan, was selected. It is located about 24 mi NW of the reactor site.

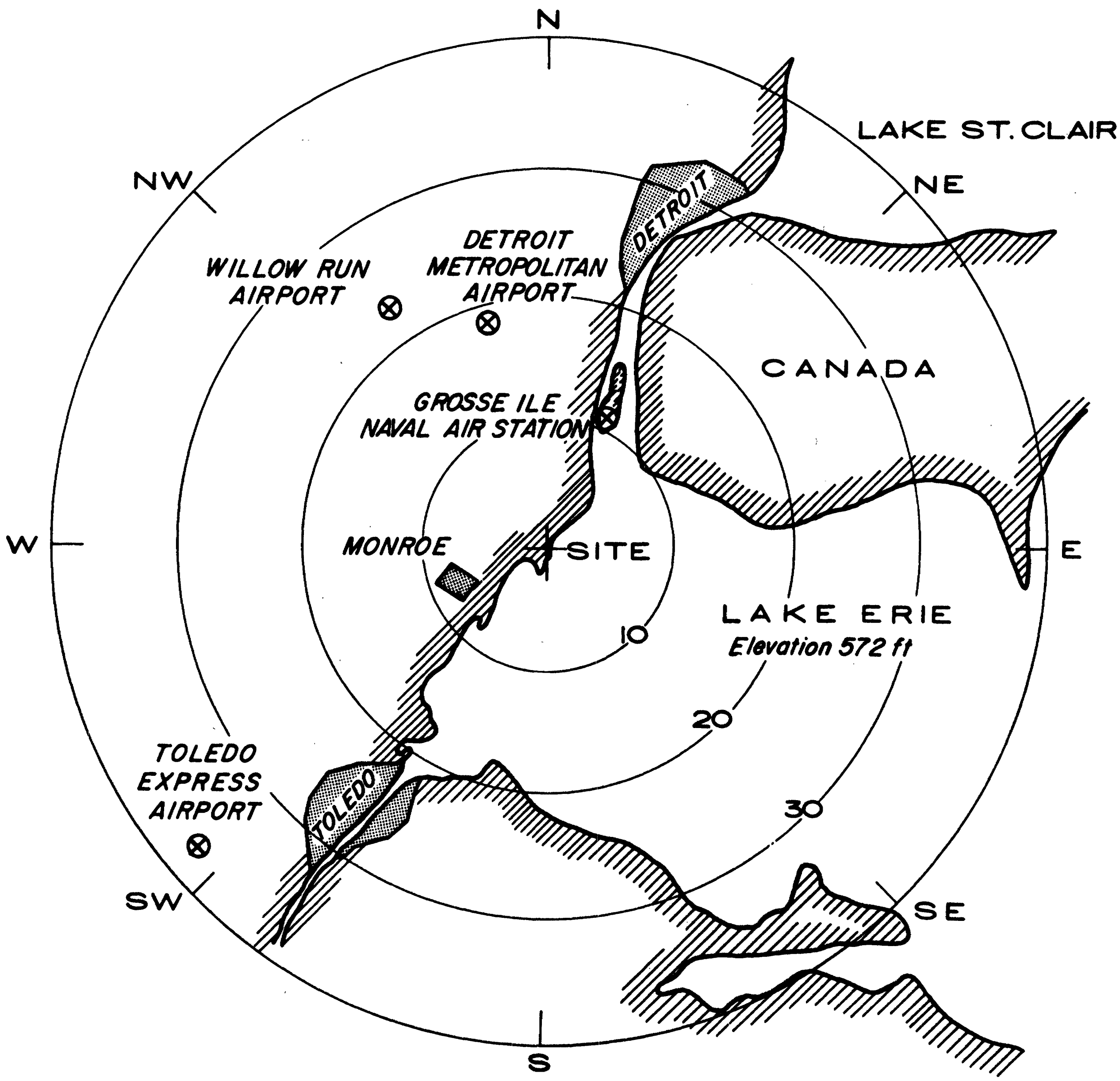

Figure 1. Area map of Enrico Fermi Nuclear Reactor site, Willow Run Airport, and surroundings.

Referring again to the parameters, $U^2/C_p\ \Delta T$, $U^2/C_p\ T$ and $\Delta T/T$, the maximum temperature (°K) for a particular day was taken as T and the average hourly wind speed (m/sec) between 1000 and 1600 hr as U . Since the buoyant force acts vertically and the inertial force acts nearly horizontally, regardless of wind direction, U was computed solely from wind speed information. The lake temperature was taken from data at the Monroe city waterworks, which have been found to be representative of the lake water temperature in the western portion of Lake Erie [1]. Putting these values in the parameter, $U^2/C_p\ \Delta T$, an index number was obtained for each day in the twelve-month period from the three summer seasons.

4. TEST CRITERIA

The synoptic criteria for selection of days with a lake breeze influence were as follows:

1. Gradient wind not from the SE quadrant.
2. Temperature of the land greater than the temperature of the water.

3a. Surface wind changed to the SE quadrant while the temperature of the land was greater than

lake temperature, and returned to a gradient condition after sunset, or

3b. Surface wind changed at least 40° to a direction from NNE clockwise to SSW due to thermal influence, then returned to a gradient condition.

4. No frontal passages occurred between 1000 and 1600 hr.

If criterion 1 or 4 was not fulfilled, the day was excluded entirely from the analysis. Each day accepted for consideration was given a L-B Index, based upon dimensional analysis, and the outcome of the synoptic analysis was then compared with it. Since the winds were averaged over seven observations, the first few observations were sometimes low enough to place the case in the lake breeze category. Also, the maximum temperature occasionally occurred too early in the day to be representative. These limitations seem to be the principal ones of the system.

In summary, the procedure was to analyze each day by two independent methods. An analysis of the climatological data established the occurrence of a lake breeze, if any. Then a numerical computation of the L-B Index was compared

to it. The strength of the lake breeze was not considered; however, one could infer the probable strength of the lake breeze from the size of the L-B Index.

5. ANALYSIS OF THE DATA

Of 369 total days in the 12 summer months, 43 days were eliminated because of an onshore gradient flow, 25 days were dropped due to missing data, and 15 days were excluded because of frontal passages. Of the 286 days analyzed, there was disagreement between the two categories on but 20, hereinafter referred to as "Unstable Parameter Days." Table 1 gives a detailed breakdown, by months, of how the days were classified. This table shows August to be the month during which almost 50 per cent of the unstable cases occurred.

Fig. 2-5 relates the dimensionless parameters, $\Delta T/T$ and $U^2/C_p T$, on a monthly basis for 1957-1959, inclusive. The lake breeze days are observed to lie to the right of the line of demarcation corresponding to $U^2/C_p \Delta T = 3$, and the non-lake breeze days to the left, excepting the 20 unstable parameter days. Only three of the latter cases are seriously far removed from the line, one of them being in June and two in August.

TABLE 1

Classification of all days, month by month, in the period of investigation

	1957				1958				1959				
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug	TOTAL
Gradient Cases	4	1	2	2	5	3	4	6	6	5	4	1	43
Frontal Passages	2	1	1	2	2	1	1	2	2	1			15
Missing Data											2	23	25
Analyzed Cases	25	28	28	27	24	26	26	23	23	24	25	7	286
Totals	31	30	31	31	31	30	31	31	31	30	31	31	369
Lake Breeze Cases	3	10	11	8	3	8	9	7	3	7	8	1	77
Unstable Parameter		1		4	2	3	1	4	1	2	1		20

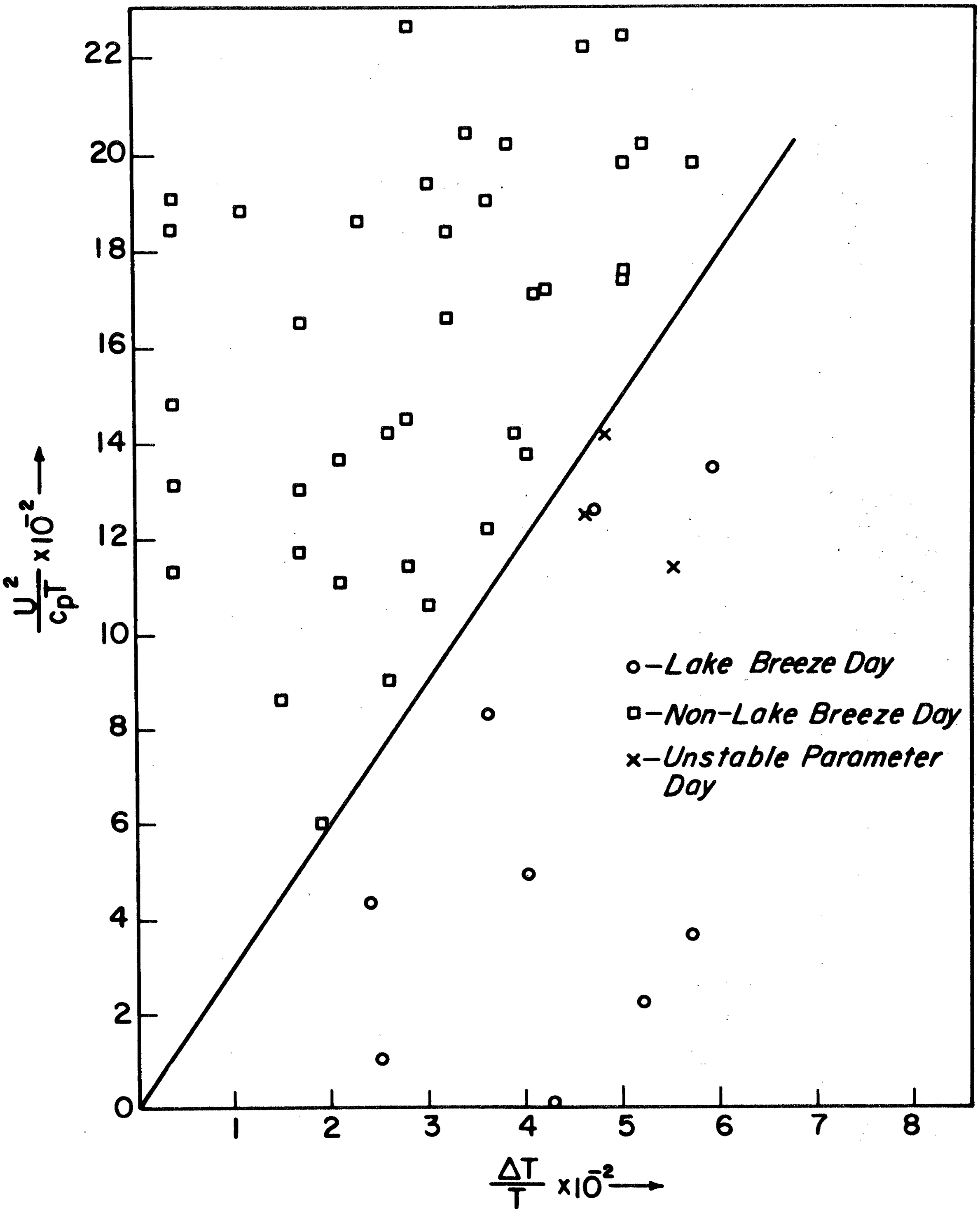

Figure 2. A plot of $\Delta T/T$ versus $U^2/C_p\ T$, representing buoyancy forces versus inertial forces, respectively, at the reactor site during the combined Mays for 1957-1959. The critical value, $U^2/C_p\ \Delta T = 3.0$, is represented by the diagonal line.

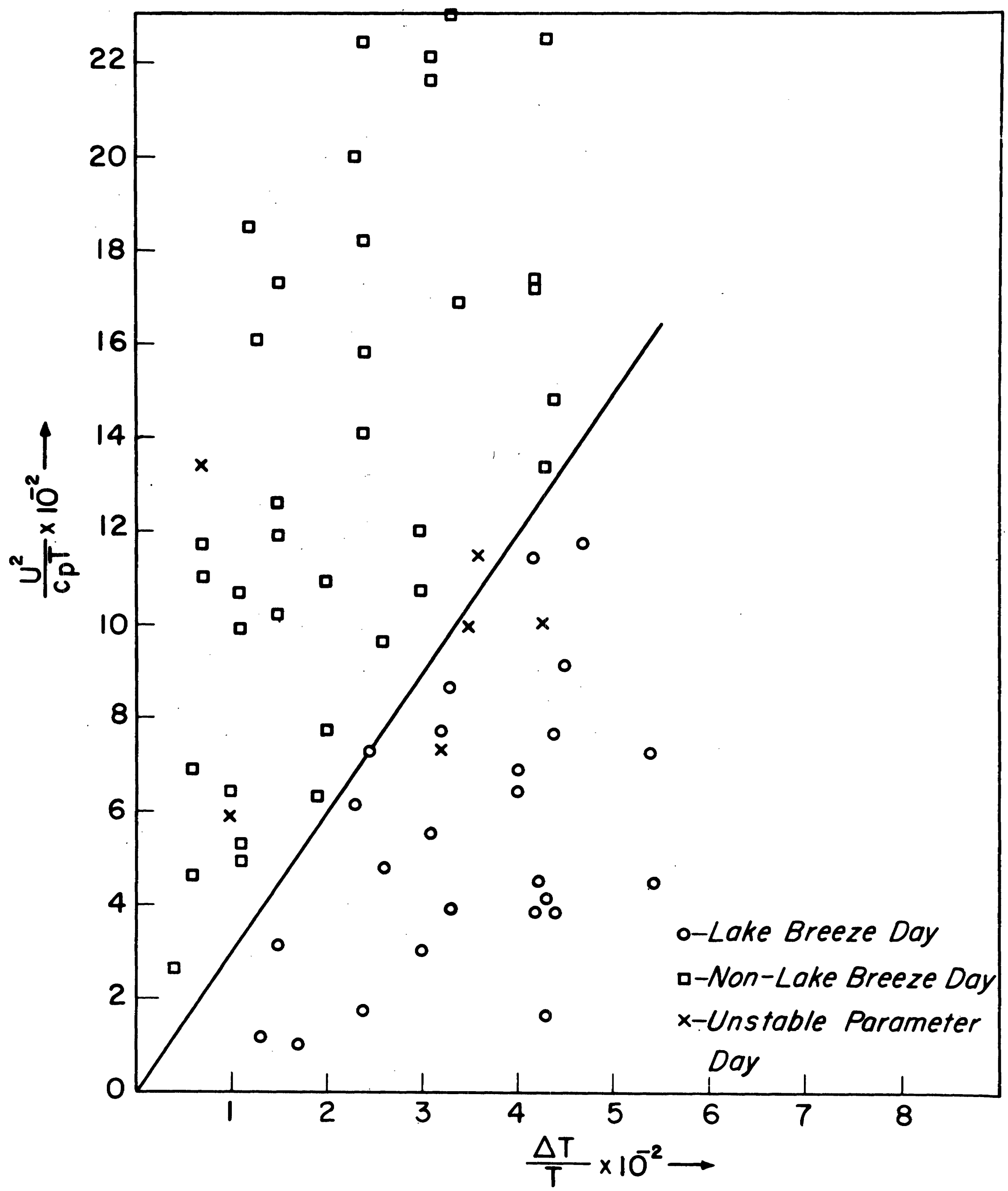

Figure 3. A plot of $\Delta T/T$ versus $U^2/C_p T$, representing buoyancy forces versus inertial forces, respectively, at the reactor site during the combined Junes for 1957-1959. The critical value, $U^2/C_p \Delta T = 3.0$, is represented by the diagonal line.

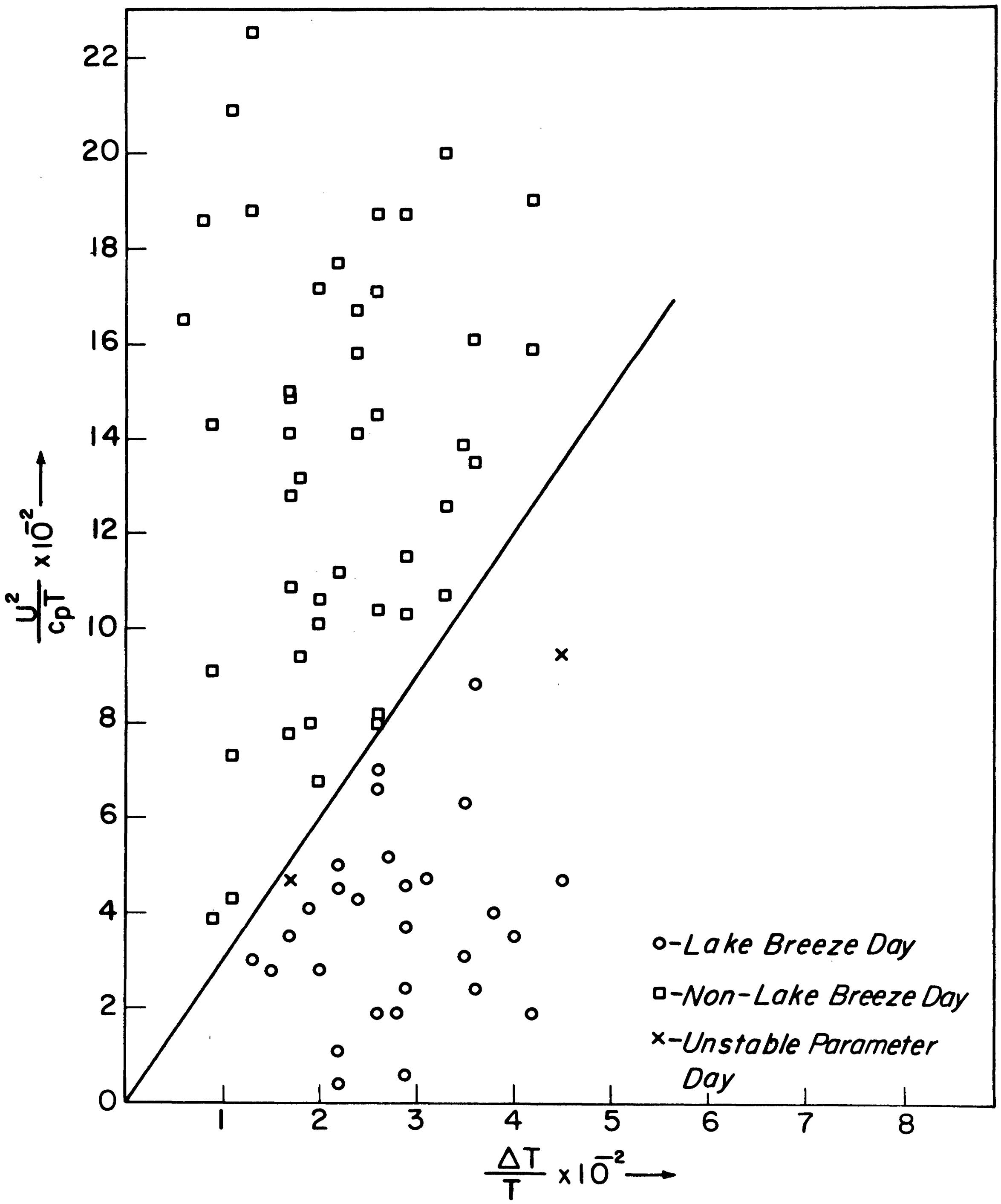

Figure 4. A plot of $\Delta T/T$ versus $U^2/C_p\,T$, representing buoyancy forces versus inertial forces, respectively, at the reactor site during the combined Julys for 1957-1959. The critical value, $U^2/C_p\,\Delta T = 3.0$, is represented by the diagonal line.

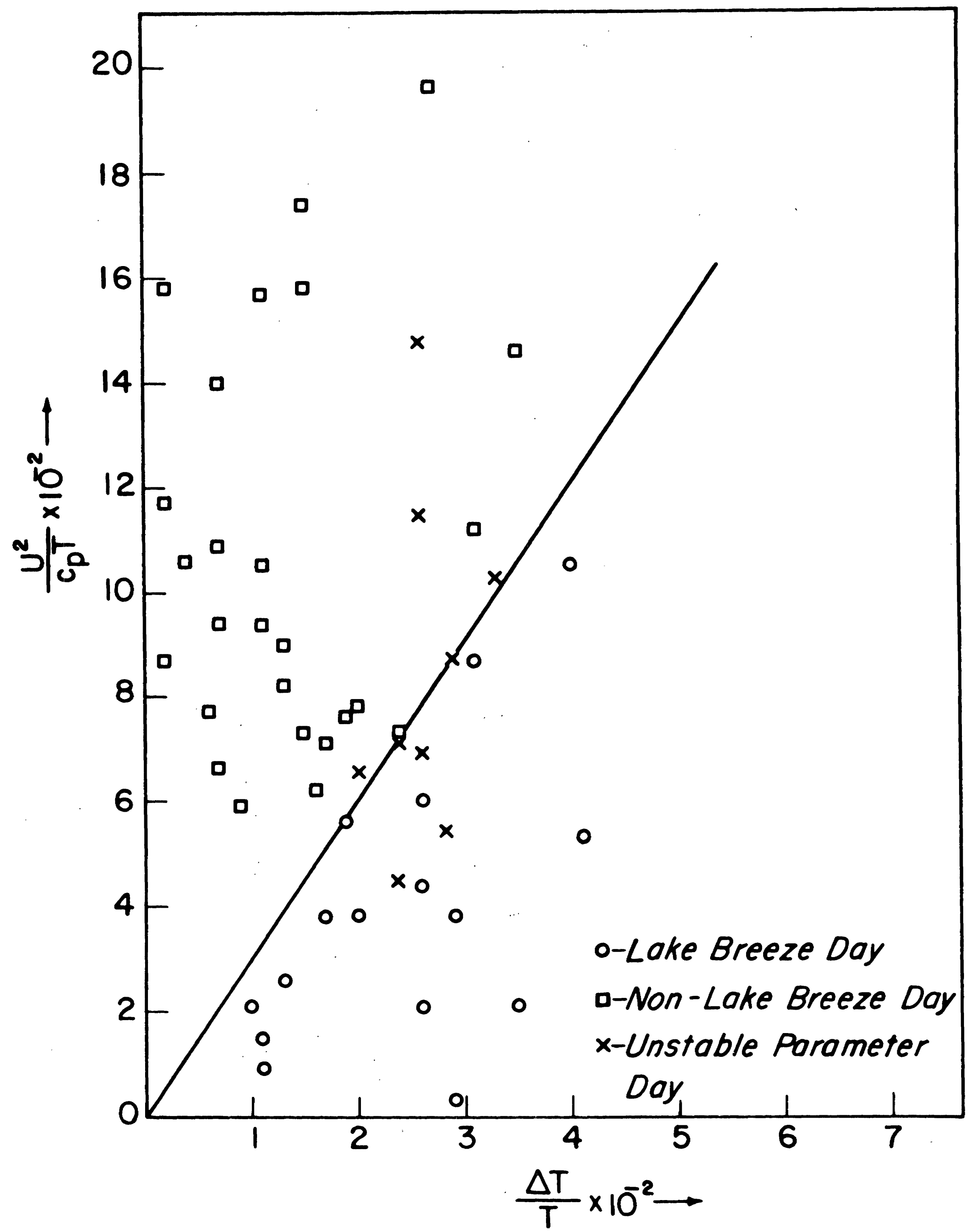

Figure 5. A plot of $\Delta T/T$ versus $U^2/C_p\ T$, representing buoyancy forces versus inertial forces, respectively, at the reactor site during the combined Augusts for 1957-1958 and August 1-8, 1959. The critical value, $U^2/C_p\ \Delta T = 3.0$, is represented by the diagonal line.

Table 2 gives the verification scores for Fig. 2-5, combined, in percentages of the total number of analyzed cases.

TABLE 2

Classification of Analyzed Cases

	Percentage of Total
Stable parameter days	92
Unstable parameter days	8
TOTAL	100

Fig. 6-9 show the relationship between the L-B Index, $U^2/C_p\ \Delta T$, and the dimensionless parameter, $U^2/C_p\ T$, for the combined Mays, Junes, Julys and Augusts of 1957-1959. Fig. 10-13 relate the L-B Index to $\Delta T/T$ for the same combined months of these years. Between May and August, certain trends are seen in all three kinds of scatter diagrams. First, the number of lake breeze cases rises to a maximum in June-July, then dwindles in August. Second, the points tend to condense toward the origin in each succeeding month, reflecting the decrease of the wind speed at Willow Run as well as the decrease of ΔT . The latter decrease is attributable to an

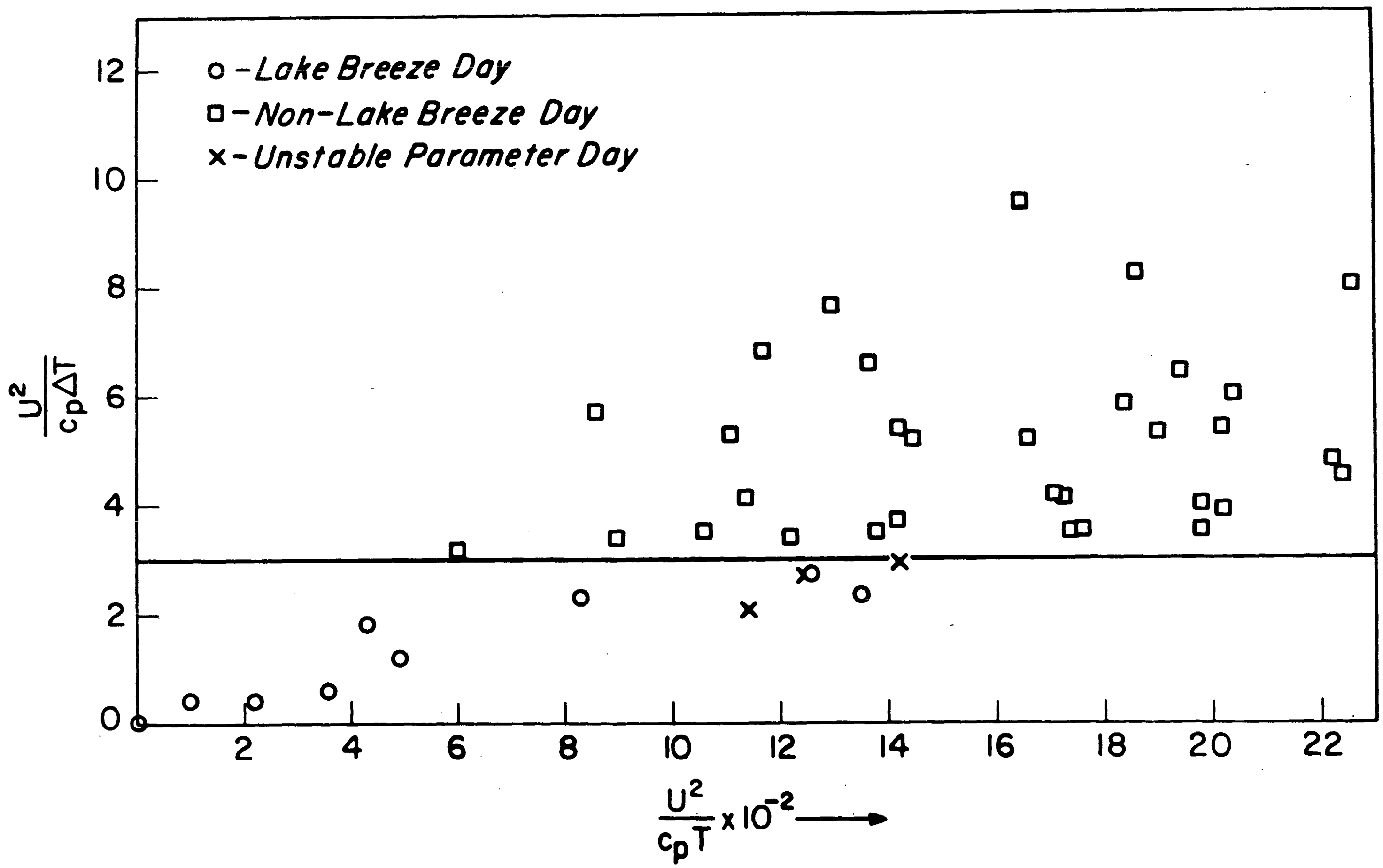

Figure 6. A plot of $U^2/C_p\ T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$, at the reactor site during the combined Mays for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

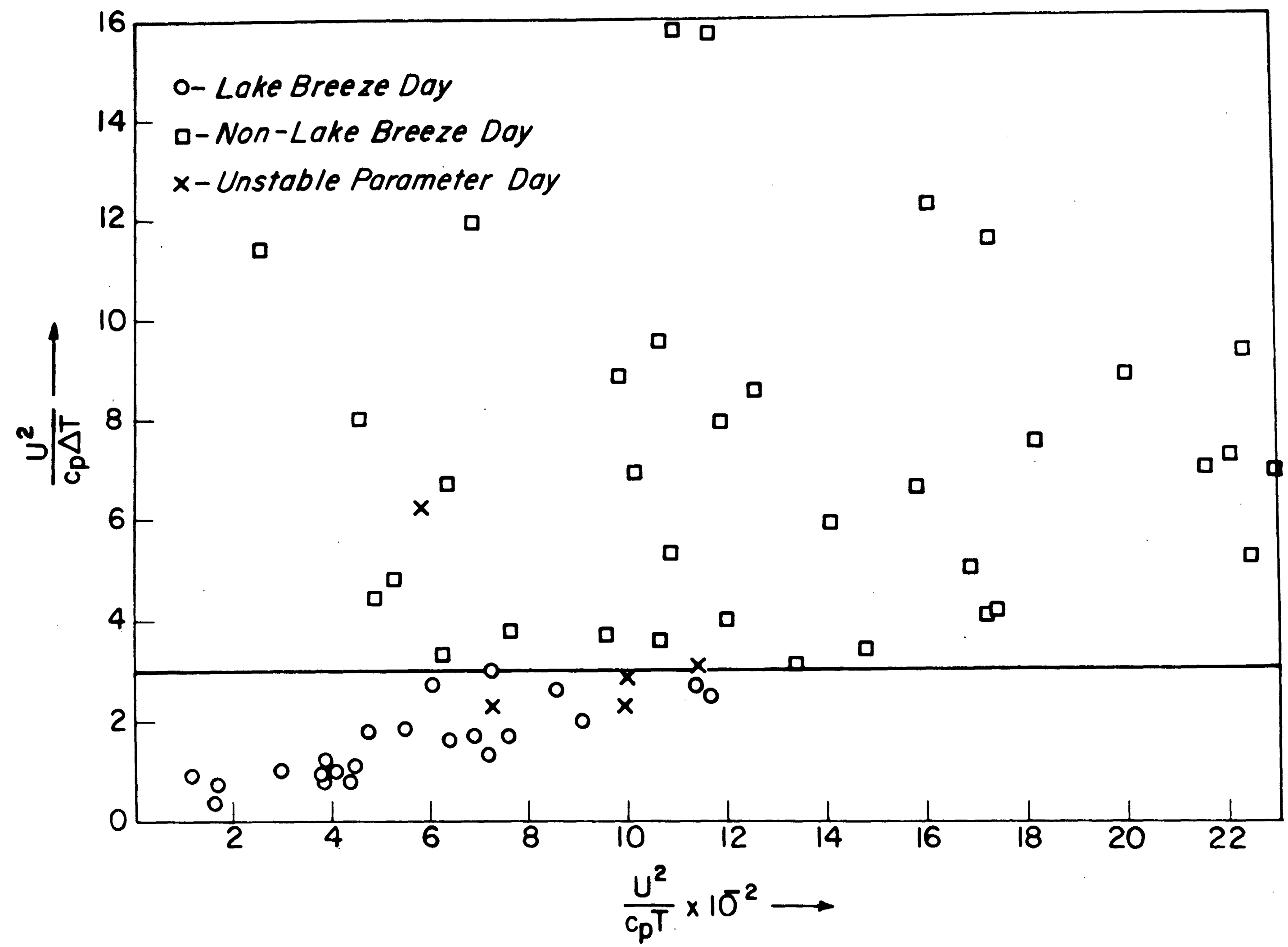

Figure 7. A plot of $U^2/C_p\ T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$, at the reactor site during the combined Junes for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

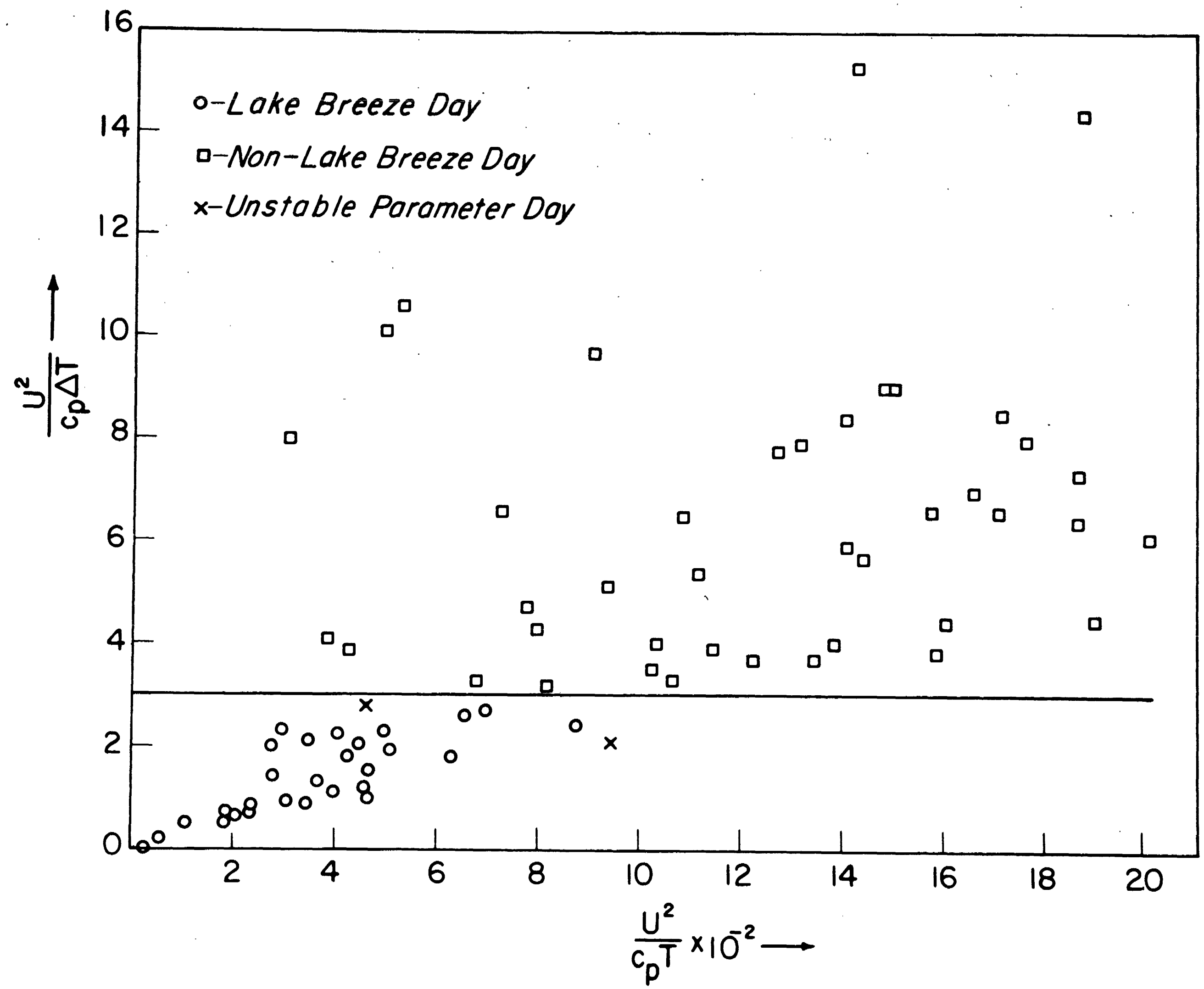

Figure 8. A plot of $U^2/C_p\ T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$, at the reactor site during the combined Julys for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

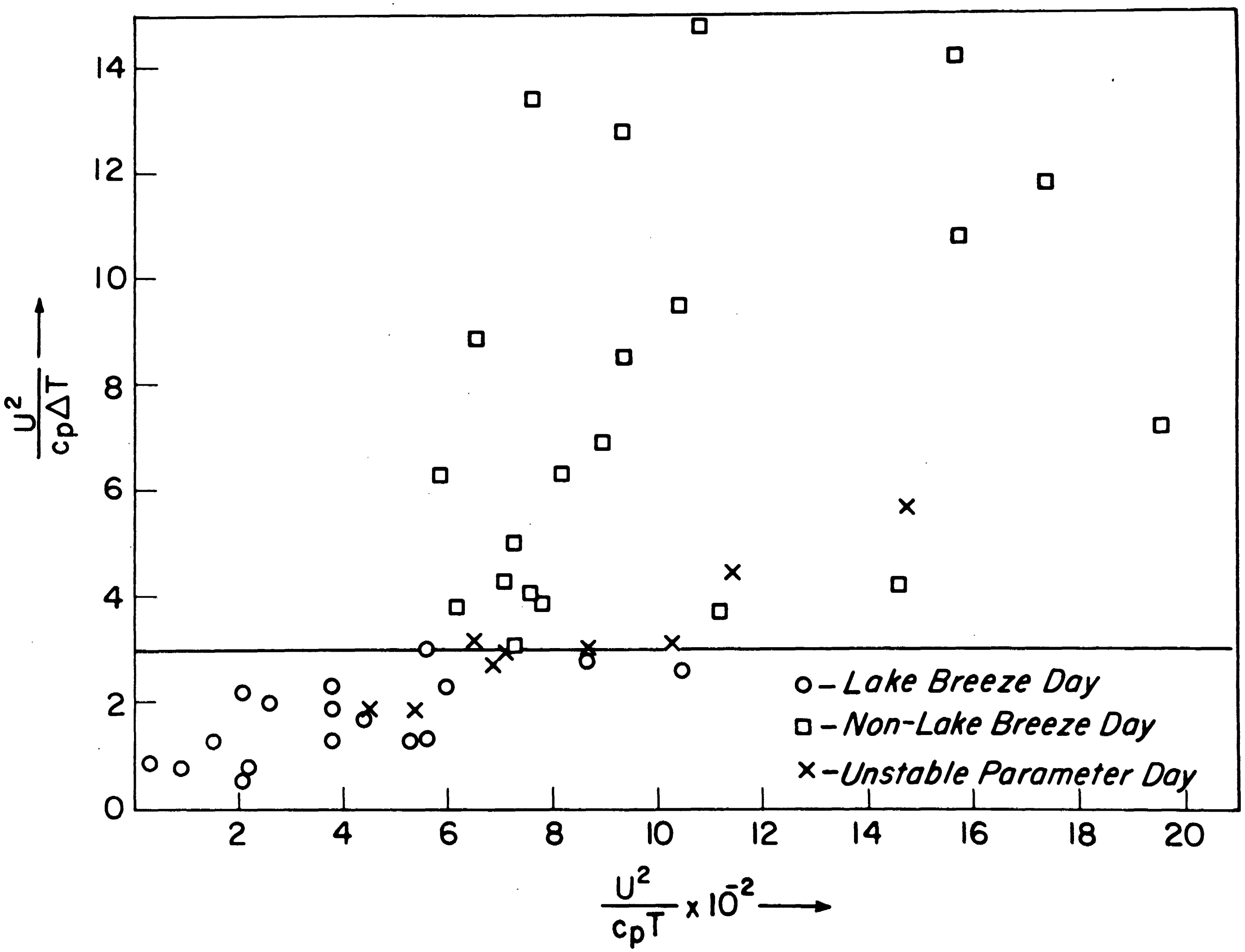

Figure 9. A plot of $U^2/C_p\ T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$, at the reactor site during the combined Augusts for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

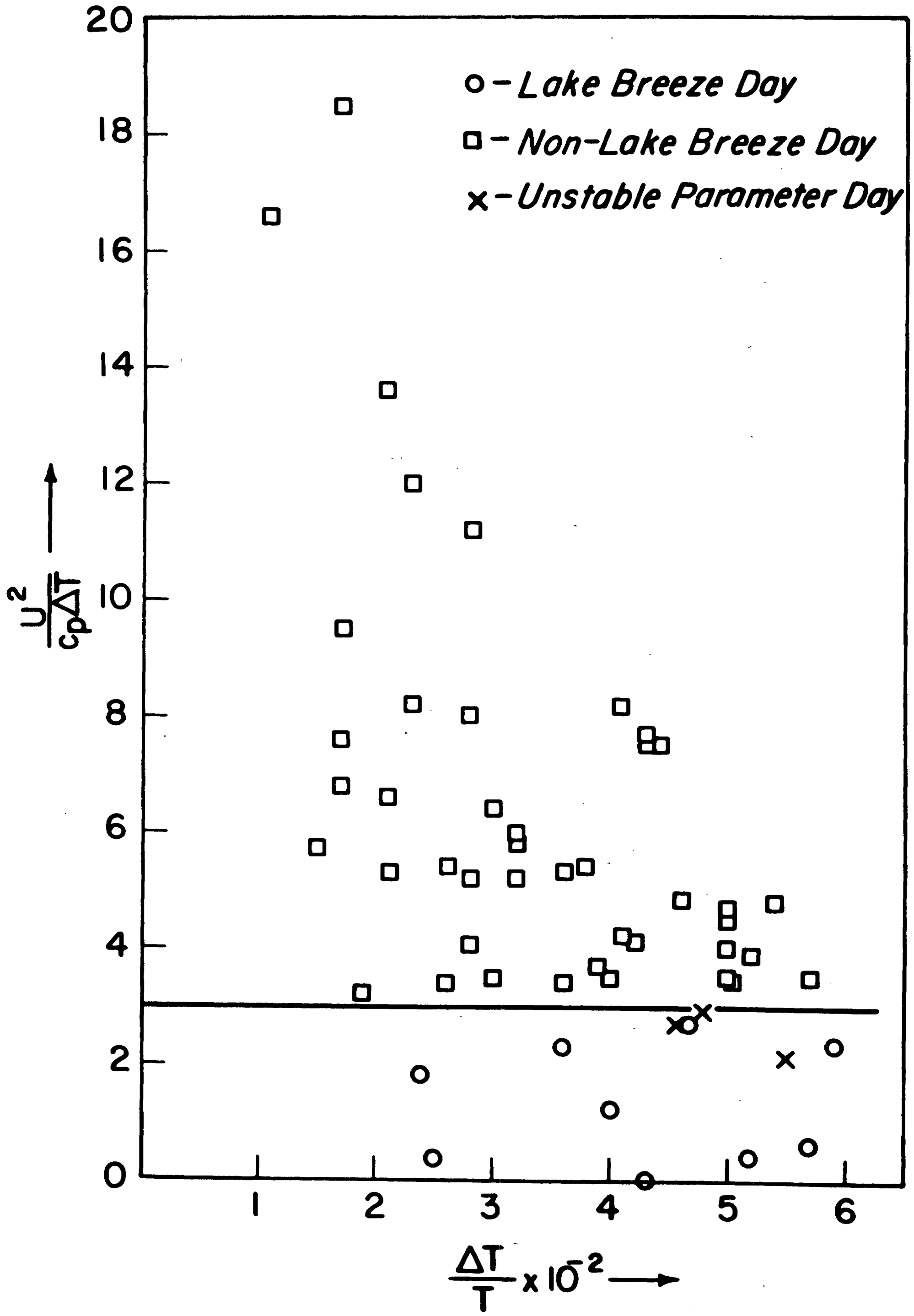

Figure 10. A plot of $\Delta T/T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$ at the reactor site during the combined Mays for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

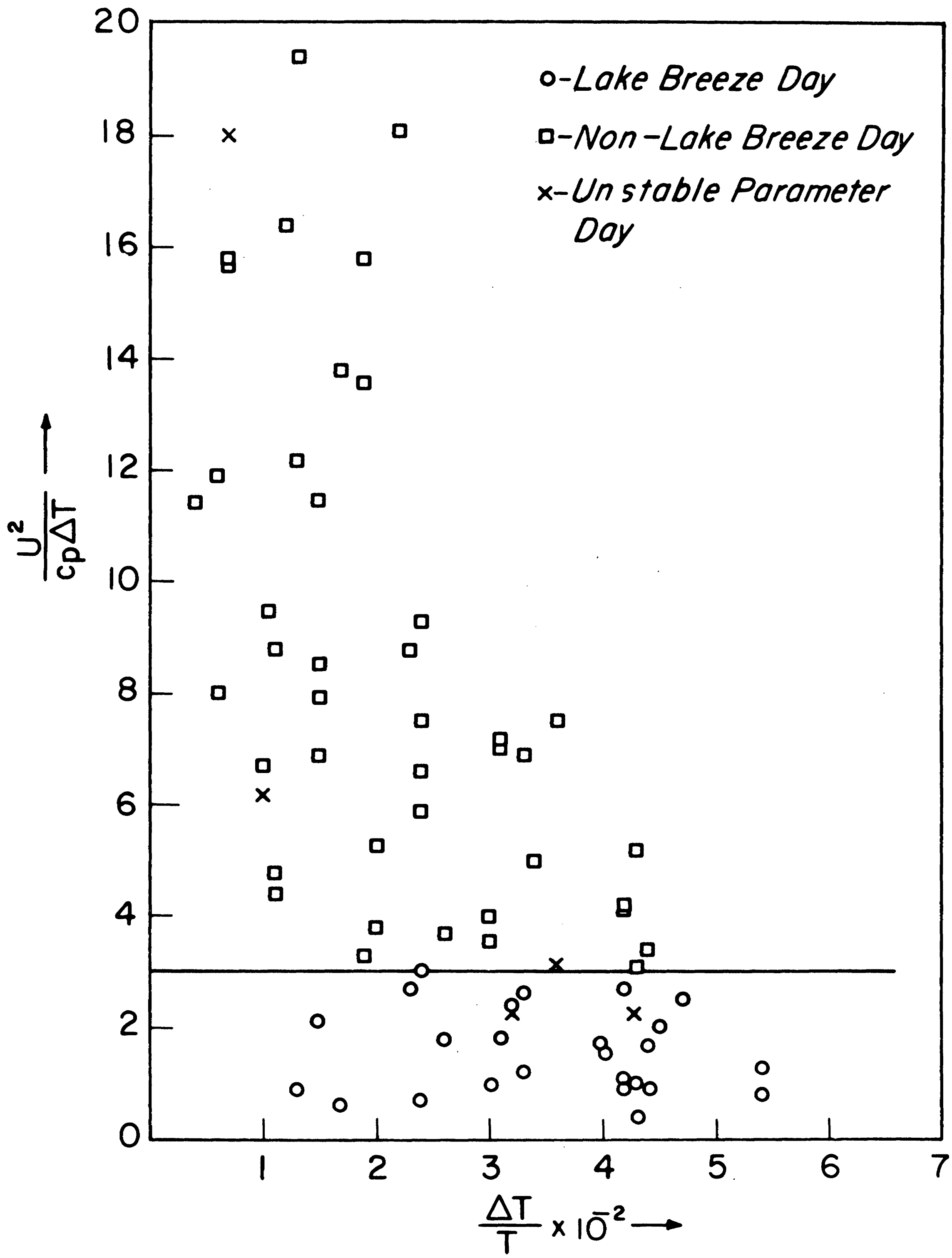

Figure 11. A plot of $\Delta T/T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$ at the reactor site during the combined Junes for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

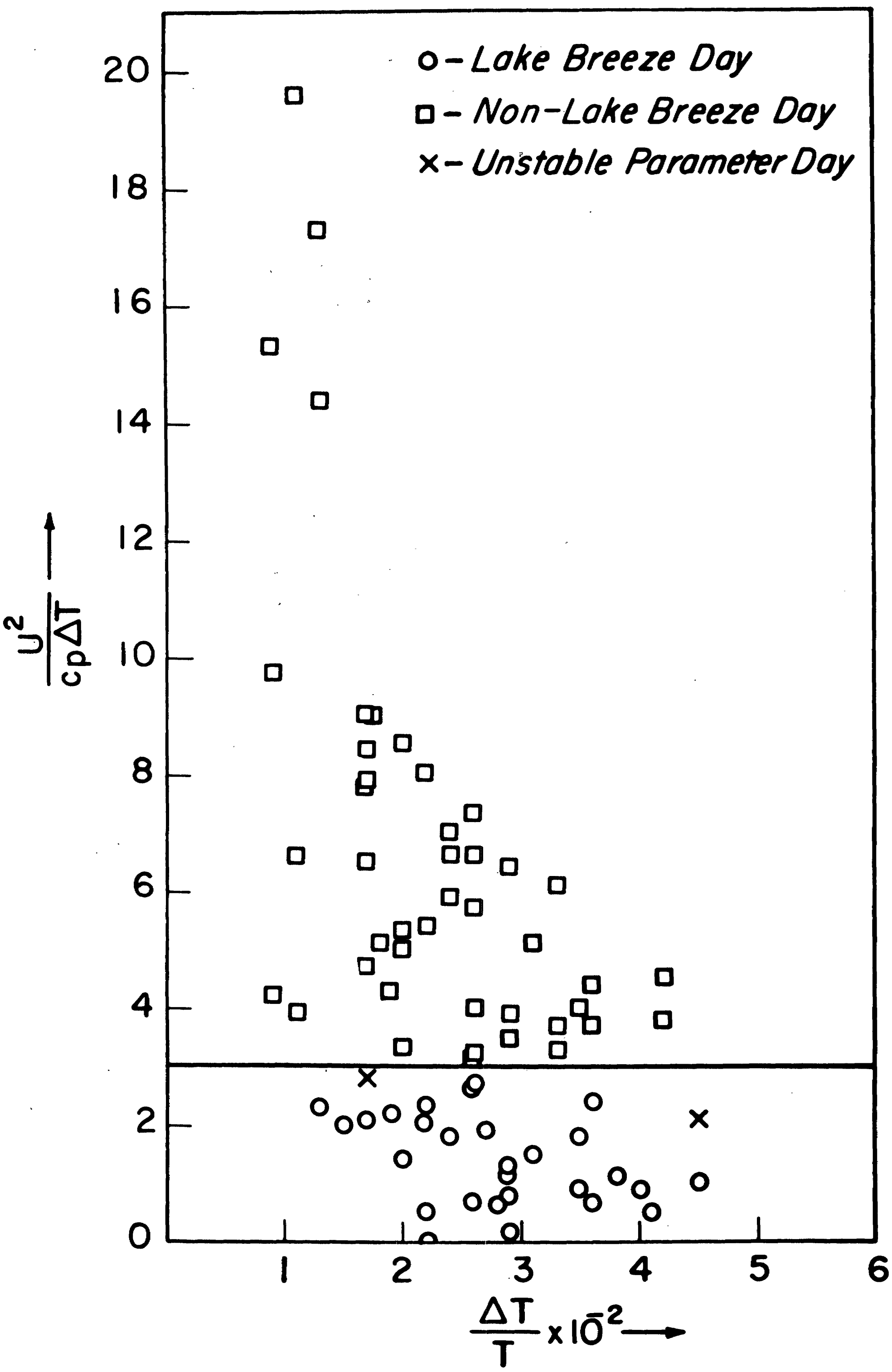

Figure 12. A plot of $\Delta T/T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$ at the reactor site during the combined Julys for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

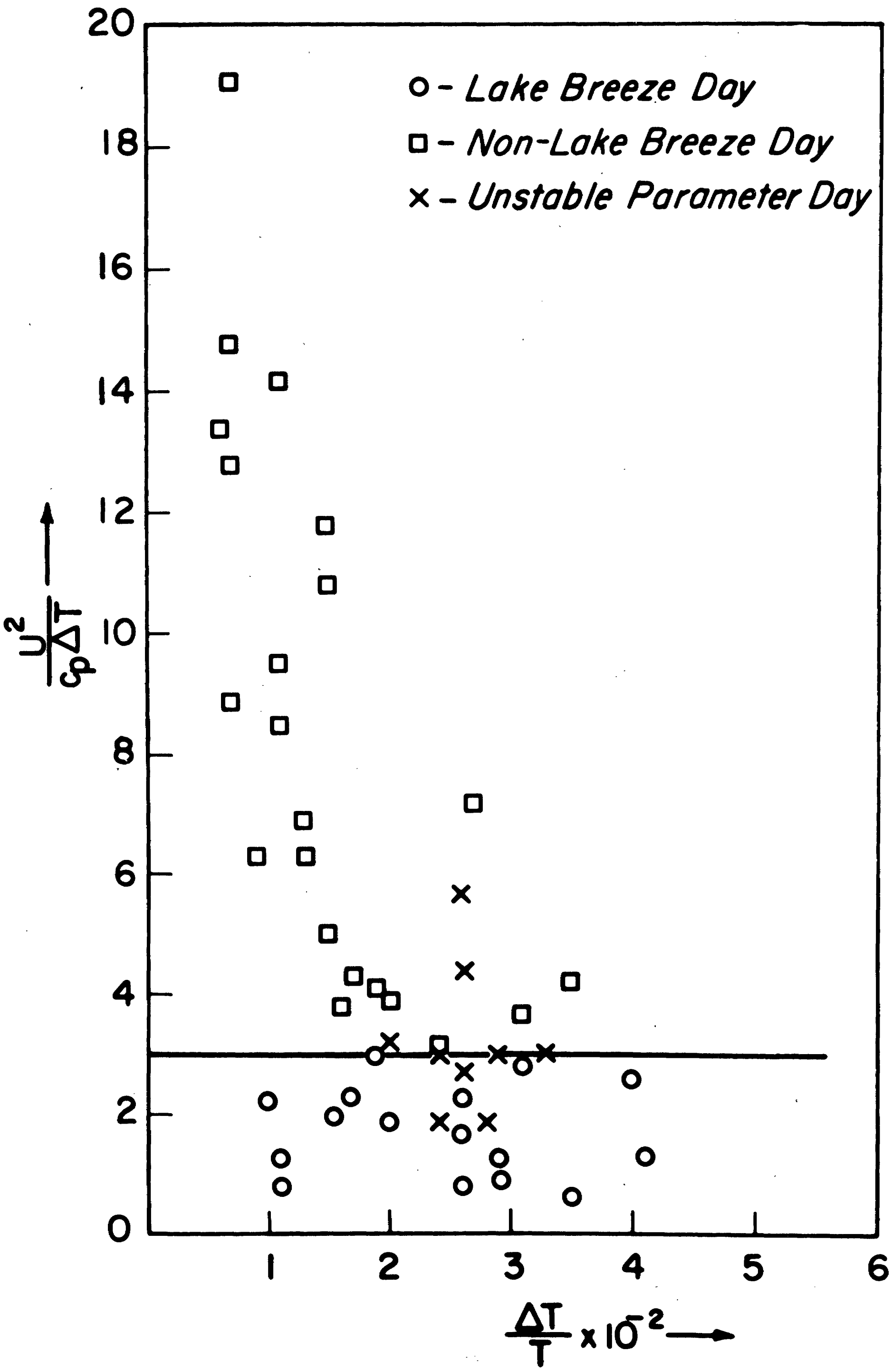

Figure 13. A plot of $\Delta T/T$ versus the Lake Breeze Index, $U^2/C_p\ \Delta T$ at the reactor site during the combined Augusts for 1957-1959. The critical value of $U^2/C_p\ \Delta T = 3.0$ is represented by the horizontal line.

annual rise in lake water temperature of at least 10°C between May and August.

Appendix I summarizes the computation of the three dimensionless parameters for each month investigated.

6. DISCUSSION

Prominent on the graphs representing June is one case when the parameters were notably unstable. This day's L-B Index was 18.0, but a lake breeze occurred at Monroe from 1300 to 1500 EST. A comparison of Willow Run wind speeds with those of Toledo indicate that local effects were responsible for the large discrepancy, viz., Willow Run winds at 12 kt were double the values of the Toledo wind speeds. This difference was magnified by the U^2 term in the L-B Index, so that the parameter calculated in a similar way for Toledo gave a margina value of 3.1.

The temperature difference between the Willow Run maximum and the lake temperature for this day was but 4°F. Because of local variations between Willow Run and the shore line and the problem of representativeness, errors in ΔT of about 2°F may be expected. Then if the observed value of ΔT

is less than 6°F, the error in the ΔT term would be comparable to the measured ΔT. If the parameter, $\Delta T/T$, is less than 10^{-2}, the L-B Index tends to be unstable. However, in most of the other cases involving $\Delta T/T < 10^{-2}$, the temperature was not strongly influenced by local effects and it was representative of the area conditions. All of the other unstable cases had a L-B Index of 6.2 or less.

As was pointed out earlier, the critical value for the L-B Index was chosen to be 3.0. This gave an accuracy of 92 per cent. If, however, the region between 2.7 and 3.2 is chosen as a transition zone, the accuracy of the system would then be 97 per cent. Another item of interest is the fact that the number of occurrences of lake breeze days when the L-B Index was greater than three is less than the number of occurrences of non-lake breeze days when the L-B Index was three or less. Of the 20 unstable cases, 35 per cent were greater than three, while 65 per cent were three or less. Thus the system distinguishes non-lake breeze days somewhat better than lake breeze days. Appendix II gives a summary of the computation of the dimensionless values for each unstable day.

An outstanding feature seen in the data for days with unstable parameters is the effect of local space and time variations in the surface wind speed. For example, on May 15,

1958, increasing offshore winds at the reactor site stopped an incipient lake breeze. Such an increase in wind speed also occurred at Toledo, but the L-B Index at Willow Run was only 2.1. Half of the nonmarginal cases falling outside the transition zone in Figs. 2-13 are similar to this example. In the remaining five unstable cases, the Willow Run data were evidently unrepresentative of reactor site conditions due to more subtle effects of cloudiness and precipitation, or to a stronger basic flow at Willow Run than along the lake.

During the day, the value of the eddy diffusivity, K_m, over the lake surface is generally less than K_m over the land, and the air over the lake would be expected to be relatively stable close to the surface. However, in the L-B Index, no value of K_m is needed to distinguish between the two cases of lake breeze or non-lake breeze. Also absent are β, the coefficient of expansion of air, and k, the thermal conductivity. These parameters are but indirectly involved because of the method used to select the numerical values for U and T. This implies that the maximum temperature for the day is a good measure of the energy available for thermal effects. Thus it seems that the method of selection for T and U incorporates the other effects, and their influence is reflected in these values.

The prevailing winds in the southeastern Michigan area are southwesterly. Therefore, the meteorological measurements are usually taken from air that has had a land trajectory. Applying the L-B Index to a location where the prevailing winds are off the water would probably increase the instability of the parameters, because a representative temperature and wind speed that has not been influenced by the water mass would be difficult to find. This method would therefore be expected to produce best results when the air is not influenced by a water surface. When tried at another locality, the critical value of the L-B Index may need modification, for the local effects may well be different.

Since the L-B Index can separate the lake breeze days from non-lake breeze days successfully, it is expected that it can also distinguish land breeze that occur at night when the L-B Index would be negative. However, a different criterion for selecting the characteristic temperature and wind speed would be required. This effect was not explored in the present study.

7. SUMMARY

A dimensional analysis yielded a ratio (L-B Index) that was representative of the balance of forces that control the establishment of a lake breeze. The inertial force, $\rho U^2/2$, and the buoyant force, $\rho g \beta \Delta T$, when taken as a ratio, gives $U^2/2g \beta \Delta T$, but g is constant over the small vertical extent of the lake breeze and β is constant over the range of temperatures involved. Thus the ratio is controlled by the two terms, U^2 and ΔT. For this reason, the L-B Index is representative of the ratio of forces.

The limitations of the L-B Index are twofold in nature. First, a frontal passage may occur during late morning or afternoon hours; second, the observations from the inland station may occasionally be unrepresentative of the lake shore conditions with the lake effect removed.

A critical value for the L-B Index was found to be 3.0. If a transition zone between 2.7 and 3.2 is recognized, then the procedure has an accuracy of 97 per cent in the test period.

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APPENDIX I

A SUMMARY OF COMPUTATIONS OF THE DIMENSIONLESS PARAMETERS

TABLE I

MAY 1957

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	86	52	11.4	11.4	6.2	1.8	F
2	56	53	16.1	24.0	0.6	40.4	
3	47	53	--	--	-	--	
4	55	53	14.1	18.4	0.4	47.9	
5	61	52	11.3	11.7	1.7	6.8	
6	72	51	7.4	4.9	4.0	1.2	LB
7	78	51	14.1	17.6	5.0	3.5	
8	80	51	17.0	25.5	5.4	4.8	
9	79	52	14.0	17.4	5.0	3.5	
10	72	54	15.1	20.4	3.4	6.0	
11	57	55	11.9	13.1	0.4	34.2	
12	68	55	3.4	1.0	2.5	0.4	LB
13	78	55	11.9	12.6	4.3	2.9	G
14	75	55	11.1	11.0	3.7	2.9	F
15	71	56	18.7	31.4	2.8	11.2	
16	58	56	11.1	11.3	0.4	29.6	
17	50	58	--	--	-	--	
18	49	56	--	--	-	--	
19	49	55	--	--	-	--	
20	52	54	--	--	-	--	
21	59	53	17.7	28.8	1.1	25.1	
22	80	53	15.9	22.4	5.0	4.5	
23	72	52	15.0	20.2	3.8	5.4	
24	72	53	9.6	8.3	3.6	2.3	LB
25	71	55	14.7	19.4	3.0	6.4	
26	77	54	19.3	33.1	4.3	7.7	
27	58	55	16.4	24.8	0.6	41.9	
28	71	57	6.4	3.7	2.6	1.4	G
29	75	56	11.7	12.2	3.6	3.4	
30	82	56	6.9	3.9	4.5	0.9	G
31	78	57	10.1	9.0	3.9	2.3	G

G = Gradient Case LB = Lake Breeze Day

F = Frontal Passage U = Unstable Case

TABLE II

JUNE 1957

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	10^{-2} x $\frac{\Delta T}{T}$	10^{-2} x $\frac{U^2}{C_p \Delta T}$	Type
1	71	58	6.0	3.3	2.4	1.3	F
2	66	58	13.7	17.3	1.5	11.5	
3	75	59	5.7	3.0	3.0	1.0	LB
4	83	59	6.4	3.8	4.4	0.9	LB
5	82	59	4.1	1.6	4.3	0.4	LB
6	82	59	6.7	4.1	4.3	1.0	LB
7	66	60	10.6	10.7	1.1	9.5	
8	70	60	18.0	30.0	1.9	15.8	
9	68	60	11.3	11.9	1.5	7.9	
10	84	60	9.3	7.6	4.4	1.7	LB
11	76	60	13.7	16.9	3.4	5.0	
12	78	61	7.7	5.4	3.1	1.7	G
13	82	61	13.9	17.2	4.2	4.1	
14	86	62	13.0	14.8	4.4	3.4	
15	85	63	8.4	6.4	4.0	1.6	LB
16	94	64	7.1	4.4	5.4	0.8	LB
17	95	65	9.0	7.2	5.4	1.3	LB
18	89	66	11.3	11.4	4.2	2.7	LB
19	75	66	16.0	23.2	1.7	13.8	
20	81	67	7.4	4.8	2.6	1.8	LB
21	88	68	11.4	11.4	3.6	3.1	U
22	91	68	14.1	17.4	4.2	4.2	
23	87	70	15.6	21.6	3.1	7.0	
24	68	70	--	--	-	--	
25	74	70	11.1	11.0	0.7	15.8	
26	83	70	13.4	15.8	2.4	6.6	
27	73	70	7.1	4.6	0.6	8.0	
28	69	69	--	--	-	--	
29	81	69	21.4	40.3	2.2	18.1	
30	81	68	15.4	22.4	2.4	9.3	

G = Gradient Case
F = Frontal Passage
LB = Lake Breeze Day
U = Unstable Case

TABLE III

JULY 1957

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	78	68	9.3	8.0	1.9	4.3	
2	84	68	6.4	3.7	2.9	1.3	LB
3	88	68	13.4	16.1	3.6	4.4	
4	84	68	11.4	11.5	2.9	3.9	
5	76	68	21.3	41.4	1.5	28.0	
6	83	69	9.4	8.0	2.6	3.1	
7	90	69	7.1	4.5	3.8	1.2	G
8	80	69	10.6	10.1	2.0	5.0	
9	82	70	13.9	17.7	2.2	8.0	
10	78	69	11.0	10.9	1.7	6.5	
11	75	70	9.9	9.1	0.9	9.7	
12	89	70	8.3	6.3	3.5	1.8	LB
13	80	70	6.6	4.1	1.9	2.2	LB
14	90	69	6.7	4.0	3.8	1.1	LB
15	78	69	12.6	14.1	1.7	8.4	
16	80	69	8.6	6.8	2.0	3.3	
17	82	69	13.7	16.7	2.4	7.0	
18	88	69	12.6	13.9	3.5	4.0	
19	93	70	4.6	1.9	4.2	0.5	LB
20	96	71	7.4	4.7	4.5	1.0	LB
21	94	71	13.4	15.9	4.2	3.8	
22	85	72	8.4	6.4	2.4	2.7	F
23	74	71	16.1	23.2	0.6	40.5	
24	78	71	14.4	18.8	1.3	14.4	
25	80	71	6.3	3.9	1.7	2.3	G
26	85	71	4.6	1.9	2.6	0.7	LB
27	87	71	6.4	4.6	2.9	1.2	LB
28	90	71	6.0	3.1	3.5	0.9	LB
29	93	71	6.3	3.5	4.0	0.9	LB
30	92	72	10.0	8.8	3.6	2.4	LB
31	86	72	9.7	8.2	2.6	3.2	

G = Gradient Case
F = Frontal Passage
LB = Lake Breeze Day
U = Unstable Case

TABLE IV

AUGUST 1957

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	10^{-2} x $\frac{\Delta T}{T}$	10^{-2} x $\frac{U^2}{C_p \Delta T}$	Type
1	88	72	5.6	0.3	2.9	0.9	LB
2	91	74	10.0	8.7	3.1	2.8	LB
3	92	75	11.4	11.2	3.1	3.7	
4	80	74	10.9	10.5	1.1	9.5	
5	73	74	--	--	-	--	
6	80	73	10.1	9.0	1.3	6.9	
7	84	73	8.6	6.5	2.0	3.2	U
8	86	72	8.9	6.9	2.6	2.7	U
9	91	72	13.0	14.6	3.5	4.2	
10	88	72	6.6	3.8	2.9	1.3	LB
11	91	72	4.9	2.1	3.5	0.6	LB
12	78	72	13.3	15.7	1.1	14.2	
13	77	73	11.1	10.9	0.7	14.8	
14	86	73	9.0	7.1	2.4	3.0	F
15	87	73	8.3	6.0	2.6	2.3	LB
16	78	72	10.3	9.4	1.1	8.5	
17	79	72	5.4	2.6	1.3	2.0	LB
18	79	72	9.6	8.2	1.3	6.3	
19	80	72	7.0	4.3	1.5	2.9	G
20	82	72	8.0	5.6	1.9	3.0	LB
21	82	72	9.3	7.6	1.9	4.1	
22	79	71	14.0	17.4	1.5	11.8	
23	85	71	13.0	14.8	2.6	5.7	U
24	70	71	--	--	-	--	
25	73	71	10.9	10.6	0.4	28.6	
26	83	70	9.0	7.1	2.4	3.0	U
27	71	70	11.4	11.7	0.2	57.4	
28	67	70	--	--	-	--	
29	80	70	7.3	4.7	1.9	2.5	F
30	76	70	4.1	1.5	1.1	1.3	LB
31	71	69	6.6	3.9	0.4	10.5	G

G = Gradient Case

F = Frontal Passage

LB = Lake Breeze Day

U = Unstable Case

TABLE V

MAY 1958

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	10^{-2} x $\frac{\Delta T}{T}$	10^{-2} x $\frac{U^2}{C_p \Delta T}$	Type
1	72	49	19.1	32.7	4.3	7.5	
2	61	49	--	--	-	--	G
3	76	50	12.6	14.2	4.8	2.9	U
4	54	50	16.3	24.7	0.8	32.0	
5	58	49	18.7	32.2	1.7	18.5	
6	58	49	23.0	48.7	1.7	28.0	
7	66	48	14.3	18.5	3.4	5.4	G
8	67	49	10.9	10.8	3.4	3.1	F
9	59	50	13.4	16.5	1.7	9.5	
10	81	50	15.0	19.8	5.7	3.5	
11	84	51	12.9	14.6	6.1	2.4	F
12	72	51	12.4	13.8	4.0	3.5	
13	76	53	0.7	0.0	4.3	0.0	LB
14	81	54	15.0	19.8	5.0	4.0	
15	83	53	11.4	11.4	5.5	2.1	U
16	80	52	5.0	2.2	5.2	0.4	LB
17	85	54	6.4	3.6	5.7	0.6	LB
18	79	55	19.4	33.3	4.4	7.5	
19	70	58	17.4	27.3	2.3	12.0	
20	69	59	25.9	6.0	1.9	3.2	
21	72	59	10.0	9.0	2.6	3.4	
22	68	59	12.0	13.0	1.7	7.6	
23	65	58	4.4	--	-	--	G
24	72	58	--	--	-	--	G
25	71	59	14.4	18.6	2.3	8.2	
26	68	59	--	--	-	--	G
27	81	59	13.9	17.1	4.1	4.2	
28	66	60	14.4	18.8	1.1	16.6	
29	74	60	12.6	14.2	2.6	5.4	
30	83	60	14.0	17.2	4.2	4.1	
31	81	60	12.7	14.2	3.9	3.7	

G = Gradient Case
F = Frontal Passage
LB = Lake Breeze Day
U = Unstable Case

TABLE VI

JUNE 1958

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	71	60	11.0	10.9	2.0	5.3	
2	67	61	14.3	18.5	1.2	16.4	
3	73	61	17.0	2.6	0.4	11.4	
4	85	60	4.0	1.4	4.7	0.3	G
5	78	60	16.1	23.0	3.3	6.9	
6	70	61	3.4	1.0	1.7	0.6	LB
7	78	61	9.3	7.7	3.2	2.4	LB
8	78	62	11.0	10.7	3.0	3.6	
9	68	63	8.4	6.4	1.0	6.7	
10	79	63	9.1	7.3	3.2	2.3	U
11	71	63	5.9	3.1	1.5	2.1	LB
12	74	63	6.7	4.0	2.1	2.0	G
13	77	64	14.3	18.2	2.4	7.5	
14	70	64	5.3	2.5	1.1	2.3	G
15	69	64	8.1	5.9	1.0	6.2	U
16	74	64	17.0	25.8	1.9	13.7	
17	76	64	8.3	6.1	2.3	2.7	LB
18	73	63	8.4	6.3	1.9	3.3	
19	77	64	12.6	14.1	2.4	5.9	
20	77	64	9.1	7.5	2.4	3.0	LB
21	71	65	5.7	2.9	1.1	2.6	F
22	78	65	4.4	1.7	2.4	0.7	LB
23	72	65	3.7	1.2	1.3	0.9	LB
24	72	66	7.7	5.3	1.1	4.8	
25	70	66	11.4	11.7	0.7	15.7	
26	73	65	22.4	45.0	1.5	30.2	
27	79	65	10.4	9.6	2.6	3.7	
28	82	65	7.9	5.5	3.1	1.8	LB
29	84	64	17.7	27.5	3.6	7.5	
30	89	65	10.7	10.0	4.3	2.3	U

G = Gradient Case LB = Lake Breeze Day
F = Frontal Passage U = Unstable Case

TABLE VII

JULY 1958

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	88	65	14.7	19.0	4.2	4.5	
2	92	67	10.4	9.5	4.5	2.1	U
3	72	68	14.4	18.6	0.8	24.9	
4	85	68	5.3	2.4	3.1	0.8	F
5	89	69	12.4	13.5	3.6	3.7	
6	85	69	2.7	0.6	2.9	0.2	LB
7	81	69	0.6	0.4	2.2	0.1	LB
8	78	69	6.4	3.5	1.7	2.1	LB
9	84	69	4.7	1.9	2.8	0.7	LB
10	88	70	15.1	20.1	3.3	6.1	
11	81	71	3.7	1.2	1.9	0.6	G
12	83	71	3.6	1.1	2.2	0.5	LB
13	84	71	13.3	15.8	2.4	6.6	
14	80	71	12.4	13.2	1.7	7.9	
15	87	73	13.9	17.1	2.6	6.6	
16	79	73	15.4	20.9	1.1	19.6	
17	78	73	4.3	1.6	0.9	1.7	G
18	78	73	6.7	3.9	0.9	4.2	
19	79	72	15.9	22.5	1.3	17.3	
20	75	72	13.6	16.5	0.6	28.8	
21	82	71	11.3	11.2	2.2	5.4	
22	80	70	1.7	0.3	1.9	0.1	G
23	85	69	5.3	2.4	2.9	0.8	LB
24	89	69	5.3	2.4	3.6	0.7	LB
25	84	70	9.0	7.0	2.6	2.7	LB
26	88	70	5.3	2.4	3.3	0.7	G
27	88	70	11.9	12.3	3.3	3.7	
28	80	71	13.0	15.0	1.7	9.0	
29	84	73	13.9	17.2	2.0	8.5	
30	80	73	5.9	3.0	1.3	2.3	LB
31	69	73	--	--	-	-	

G = Gradient Case LB = Lake Breeze Day
F = Frontal Passage U = Unstable Case

TABLE VIII

AUGUST 1958

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	10^{-2} x $\frac{\Delta T}{T}$	10^{-2} x $\frac{U^2}{C_p \Delta T}$	Type
1	82	72	6.9	4.1	1.9	2.2	G
2	85	71	4.6	1.8	2.6	0.7	G
3	93	72	7.7	5.3	4.1	1.3	LB
4	87	72	4.9	2.1	2.6	0.8	LB
5	87	72	15.0	19.6	2.7	7.2	
6	88	72	10.1	0.9	0.3	3.0	F
7	85	72	8.4	6.2	2.4	2.6	F
8	81	72	9.0	7.1	1.7	4.3	
9	86	73	7.1	4.5	2.4	1.9	U
10	89	73	10.0	8.7	2.9	3.0	U
11	88	73	5.6	2.7	2.7	1.0	G
12	89	73	7.9	5.4	2.8	1.9	U
13	83	74	6.6	3.8	1.7	2.3	LB
14	87	74	9.1	7.3	2.4	3.1	
15	80	74	3.1	0.9	1.1	0.8	LB
16	77	74	6.7	4.0	0.6	6.9	G
17	82	73	8.4	6.2	1.6	3.8	
18	71	72	--	--	-	-	
19	79	71	8.6	6.5	1.5	4.4	G
20	81	70	6.6	3.8	2.0	1.9	LB
21	76	71	8.1	5.9	0.9	6.3	
22	75	71	8.6	6.6	0.7	8.9	
23	78	70	7.0	4.3	1.5	2.9	G
24	73	70	9.3	7.7	0.6	13.4	
25	69	70	--	--	-	-	
26	75	70	4.9	2.1	1.0	2.2	LB
27	80	69	9.4	7.8	2.0	3.9	
28	83	69	11.4	11.5	2.6	4.4	U
29	87	69	10.9	10.3	3.3	3.1	U
30	91	69	11.0	10.5	4.0	2.6	LB
31	79	70	22.9	46.3	1.7	27.7	

G = Gradient Case LB = Lake Breeze Day

F = Frontal Passage U = Unstable Case

TABLE IX

MAY 1959

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	10^{-2} x $\frac{\Delta T}{T}$	10^{-2} x $\frac{U^2}{C_p \Delta T}$	Type
1	61	50	11.0	11.1	2.1	5.3	
2	82	50	12.4	13.5	5.9	2.3	LB
3	79	51	15.1	20.2	5.2	3.9	
4	77	52	12.4	13.6	4.7	2.9	G
5	84	52	10.9	10.4	5.9	1.8	G
6	88	53	9.7	8.2	6.4	1.3	G
7	71	54	14.3	18.4	3.2	5.8	
8	62	54	9.7	8.6	1.5	5.7	
9	67	56	17.7	28.4	2.1	13.6	
10	79	57	19.4	33.3	4.1	8.2	
11	72	57	12.7	14.5	2.8	5.2	
12	76	57	14.6	19.0	3.6	5.3	
13	72	57	15.6	22.6	2.8	8.0	
14	50	57	--	--	-	-	
15	50	57	--	--	-	-	
16	58	56	14.4	19.1	0.4	49.9	
17	67	56	12.3	13.7	2.1	6.6	
18	73	56	13.6	16.6	3.2	5.2	
19	84	57	16.4	23.6	5.0	4.7	
20	84	57	7.1	4.4	5.0	0.9	G
21	81	56	11.9	12.5	4.6	2.7	U
22	78	56	11.7	11.5	4.1	3.0	F
23	59	57	12.7	14.8	0.4	38.9	
24	72	59	6.9	4.3	2.4	1.8	LB
25	73	58	11.3	11.4	2.8	4.1	
26	81	59	11.1	10.9	4.1	2.7	G
27	85	60	15.9	22.2	4.6	4.8	
28	86	60	6.9	4.2	4.7	0.9	F
29	87	61	12.0	12.6	4.7	2.7	LB
30	77	61	10.9	10.6	3.0	3.5	
31	85	62	9.6	8.1	4.2	1.9	G

G = Gradient Case LB = Lake Breeze Day
F = Frontal Passage U = Unstable Case

TABLE X

JUNE 1959

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	75	63	15.0	20.0	2.3	8.8	
2	71	63	11.9	12.6	1.5	8.5	
3	82	64	6.6	3.9	3.3	1.2	LB
4	86	63	7.1	4.5	4.2	1.1	LB
5	86	63	6.7	3.8	4.2	0.9	LB
6	82	64	5.1	2.3	3.3	0.7	G
7	88	65	8.3	6.1	4.2	1.4	G
8	92	66	11.6	11.7	4.7	2.5	LB
9	93	68	10.3	9.1	4.5	2.0	LB
10	90	66	9.3	7.5	4.4	1.7	G
11	85	67	10.0	8.6	3.3	2.6	LB
12	88	71	15.9	22.1	3.1	7.2	
13	67	69	--	--	-	-	
14	72	68	12.3	13.4	0.7	18.0	U
15	72	68	5.9	3.0	0.7	4.1	G
16	74	67	16.9	25.5	1.3	19.4	
17	73	66	13.4	16.1	1.3	12.2	
18	72	66	10.4	9.9	1.1	8.8	
19	81	65	11.6	12.0	3.0	4.0	
20	84	65	10.6	10.0	3.5	2.9	U
21	86	66	9.7	8.2	3.7	2.3	G
22	69	66	8.7	6.9	0.6	11.9	
23	73	67	7.3	4.9	1.1	4.4	
24	75	67	10.6	10.2	1.5	6.9	
25	90	68	9.0	6.9	4.0	1.7	LB
26	81	67	9.1	7.4	2.6	2.8	G
27	91	67	12.4	13.4	4.3	3.1	
28	91	67	16.1	22.5	4.3	5.2	
29	93	67	9.3	7.5	4.7	1.6	F
30	79	68	9.4	7.7	2.0	3.8	

G = Gradient Case
F = Frontal Passage
LB = Lake Breeze Day
U = Unstable Case

TABLE XI

JULY 1959

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	88	68	11.0	10.5	3.7	2.9	G
2	82	70	7.1	4.5	2.2	2.0	LB
3	86	69	7.3	4.7	3.1	1.5	LB
4	86	70	14.6	18.7	2.9	6.4	
5	88	70	11.1	10.7	3.3	3.3	
6	80	71	13.0	14.9	1.7	9.0	
7	85	71	5.9	3.1	2.6	1.2	G
8	89	72	13.4	15.6	3.1	5.1	G
9	85	72	12.7	14.1	2.4	5.9	
10	87	73	12.9	14.5	2.6	5.7	
11	81	72	7.3	4.7	1.7	2.8	U
12	81	72	9.4	7.8	1.7	4.7	
13	84	71	8.3	6.0	2.4	2.5	
14	86	72	10.9	10.4	2.6	4.0	
15	86	72	14.6	18.7	2.6	7.3	
16	90	73	9.7	8.2	3.1	2.6	G
17	87	74	7.0	4.3	2.4	1.8	LB
18	80	74	9.1	7.3	1.1	6.6	
19	87	75	6.9	4.2	2.2	1.9	M
20	80	74	7.0	4.3	1.1	3.9	
21	87	75	7.6	5.0	2.2	2.3	LB
22	90	75	7.7	5.1	2.7	1.9	LB
23	80	75	12.7	14.3	0.9	15.3	
24	85	76	12.1	12.8	1.7	7.8	
25	76	76	--	--	-	-	
26	84	76	5.7	2.8	1.5	2.0	LB
27	86	75	5.7	2.8	2.0	1.4	LB
28	89	75	8.7	6.6	2.6	2.6	LB
29	86	75	11.0	10.6	2.0	5.3	
30	92	76	10.9	10.3	2.9	3.5	
31	86	76	10.4	9.4	1.8	5.1	

G = Gradient Case LB = Lake Breeze Day
F = Frontal Passage U = Unstable Case
M = Missing Data

TABLE XII

AUGUST 1959

Day	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$\frac{U^2}{C_p T}$	$10^{-2} \times \frac{\Delta T}{T}$	$10^{-2} \times \frac{U^2}{C_p \Delta T}$	Type
1	80	76	12.6	14.0	0.7	19.1	
2	80	76	10.3	9.4	0.7	12.8	
3	76	75	9.9	8.7	0.2	43.4	
4	82	74	9.1	7.3	1.5	5.0	
5	88	74	7.1	4.4	2.6	1.7	LB
6	88	74	6.4	3.6	2.6	1.4	G
7	76	75	13.3	15.8	0.2	78.2	
8	81	73	13.4	15.8	1.5	10.8	
9	74	73	11.9	12.7	0.2	62.6	M
10	80	72	11.0	10.7	1.5	7.3	M
11	84	72	7.4	4.8	2.2	2.2	M
12	88	72	14.1	17.3	2.9	5.9	M
13	92	73	7.0	4.2	1.6	2.6	M
14	92	73	13.0	14.6	1.6	9.0	M
15	89	73	14.4	18.0	2.9	6.2	M
16	85	74	12.4	13.5	2.0	6.7	M
17	83	74	13.7	16.5	1.7	9.9	M
18	86	74	3.9	1.3	2.2	0.6	M
19	88	75	8.4	6.1	2.4	2.6	M
20	92	76	11.4	11.2	2.9	3.9	M
21	92	76	12.1	12.7	2.9	4.4	M
22	94	76	8.6	6.4	3.3	2.0	M
23	92	76	9.1	7.1	2.9	2.5	M
24	93	76	6.3	3.4	3.1	1.1	M
25	95	79	8.1	5.6	2.9	2.0	M
26	92	79	12.4	13.3	2.3	5.7	M
27	88	79	9.1	7.2	1.6	4.4	M
28	88	79	9.7	8.2	1.6	5.0	M
29	90	79	9.9	8.5	2.0	4.3	M
30	88	79	4.1	1.5	1.6	0.9	M
31	81	79	8.7	6.7	0.4	18.2	M

G = Gradient Case
F = Frontal Passage
M = Missing Data

LB = Lake Breeze Day
U = Unstable Case

APPENDIX II

A SUMMARY OF COMPUTATIONS OF THE DIMENSIONLESS VALUES FOR EACH UNSTABLE CASE

TABLE I

	T_{max} (°F)	T_{lake} (°F)	U (Kt)	$10^{-2} \cdot \frac{\Delta T}{T}$	$10^{-2} \cdot \frac{U^2}{C_p T}$	$\frac{U^2}{C_p \Delta T}$
14 June 1959	72	68	12.3	0.7	13.4	18.0
15 June 1958	69	64	8.1	1.0	5.9	6.2
23 Aug 1957	85	71	13.0	2.6	14.8	5.7
28 Aug 1958	83	69	11.4	2.6	11.5	4.4
7 Aug 1957	84	73	8.6	2.0	6.5	3.2
29 Aug 1958	87	69	10.9	3.3	10.3	3.1
21 June 1957	88	68	11.4	3.6	11.4	3.1
10 Aug 1958	89	73	10.0	2.9	8.7	3.0
26 Aug 1957	83	70	9.0	2.4	7.1	3.0
3 May 1958	76	50	12.6	4.8	14.2	2.9
20 June 1959	84	65	10.6	3.5	10.0	2.9
11 July 1959	81	72	7.3	1.7	4.7	2.8
21 May 1959	81	56	11.9	4.6	12.5	2.7
8 Aug 1957	86	72	8.9	2.6	6.9	2.7
30 June 1958	89	65	10.7	4.3	10.0	2.3
10 June 1958	79	63	9.1	3.2	7.3	2.3
15 May 1958	83	53	11.4	5.5	11.4	2.1
2 July 1958	92	67	10.4	4.5	9.5	2.1
12 Aug 1958	89	73	7.9	2.8	5.4	1.9
9 Aug 1958	86	73	7.1	2.4	4.5	1.9

A listing of all unstable parameter cases.